1 Introduction

1.1 The determination of maximum and minimum dry densities of sand is critical to the calculation of relative density D_r of reconstituted test specimens for testing in the laboratory.

1.2 This technical procedure details the method for determining the nominal maximum dry density of sand without crushing.

1.3 This method is only suitable for sands (material passing a 2 mm test sieve). The method described is valid for sands with up to 12% fines content (particles passing a 0.063 mm sieve).

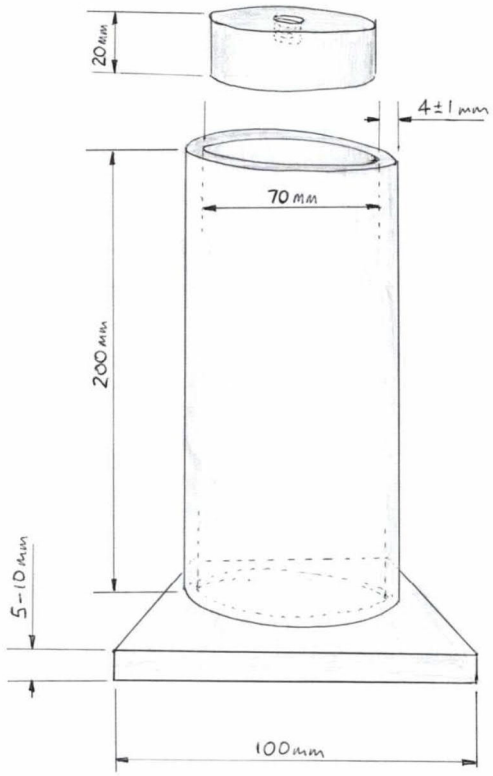
1.4 If it is expected that the sand is crushable then grain size distributions should be performed before and after testing to establish if crushing has taken place or not.

1.5 It is up to the individual laboratory to ensure all health and safety requirements are met regarding the use of their equipment.

2 Apparatus

2.1 A vibratory device, such as a sieve shaking device used for test sieves up to 200 mm diameter. The device should have variable vertical amplitude control, ideally in the range 0 – 3 mm and a frequency of 50 Hz. In the remainder of this document the term 'shaker' will be used. The amplitude of the shaker as per its settings should be checked regularly (at least 6 monthly) to ensure the required amplitudes are being achieved.

2.2 A flat-bottomed, straight sided translucent plastic mould nominally 70 ± 1 mm inner diameter, 200 ± 2 mm tall, with a wall thickness 4 ± 1 mm. The bottom plate should be nominally 100 mm square and 5 – 10 mm thick, optionally with rounded corners. See sketch of mould and top disc in Figure 1 .



The volume and cross-sectional area of the mould shall be calibrated before initial use. Calibration of the mould shall be carried out annually or after 250 tests (equivalent to 500 runs) whichever occurs first. Determine the volume of the mould by both the direct-measurement method and by water filling method. If the difference between the volumes is greater than 0.5% the calibrations should be repeated. If after repeating the difference exceeds 0.5% then the mould should be replaced.

Figure 1 Sketch of mould and top disc.

2.3 Equipment to clamp the base of the mould to the shaker.

2.4 A plastic disc of uniform thickness, nominally 20 mm and maximum variation in thickness 0.2 mm. The diameter shall closely fit the internal diameter of the mould to be used. The diameter of the disc shall be of a sufficiently close fit so as to prevent as far as possible the escape of test material around the periphery of the disc during the test procedure, to avoid friction and to allow removal from the mould; a diameter up to 0.5 mm smaller than the mould has been found to be suitable. This may be threaded on one face to allow a metal rod to be screwed into the disc to allow for easy removal of the disc after testing. Checking of the disc geometry shall be carried out annually or after 250 tests (equivalent to 500 runs) whichever occurs first.

2.5 Filter paper with a diameter of the plastic disc + 2 mm (tentative specification: thickness 0.16 mm, such as Wathman 50 or 54). Double sided tape may be needed, see clause 4.1.

2.6 A cylindrical surcharge weight to give a surcharge of 7 kPa ± 2% (equivalent to 2750 g mass using 70 mm diameter mould). The surcharge weight shall be of a suitable height and diameter to allow the weight to sit in the mould without causing it to topple during test.

2.7 Calibrated balance of suitable range, readable to 0.1 g.

2.8 A calibrated depth gauge or measuring caliper with a depth gauge blade, capable of reading to 0.01 mm.

2.9 A calibrated drying oven capable of maintaining a temperature of 105 to 110 °C. The oven shall be of forced air type and shall be capable of maintaining a uniform temperature within the useable oven space.

2.10 Laboratory wash-bottle with distilled, deionized or demineralized water.

2.11 Airtight plastic containers of approximately 2 L capacity.

2.12 A small scoop, plastic foil and non-corrosive trays.

2.13 Syringe (or similar) for suctioning excess water and sand.

3 Sample Preparation

3.1 Obtain a test sample of sufficient quantity to provide at least 1 kg of dry material passing a 2 mm test sieve (this provides sufficient for two determinations, but additional determinations may be required if the densities from the first two determinations are not sufficiently close to each other).

3.2 The sample shall be dried to a constant mass according to ISO 17892-1. If the sample has a fines content exceeding 5%, the sample should be air dried or dried at a low temperature (50°C) and the sand then gently pestled in a mortar before final drying to a constant mass according to ISO 17892-1.

3.3 Weigh and record entire sample, M_{all}

3.4 Pass the oven-dried test sample through the 2 mm test sieve. Overloading of the test sieve must be avoided by taking individual portions of test sample of less than the maximum permissible mass and performing the sieving procedure in several operations.

3.5 Weigh and record the sieved sample, M_{sieved}

3.6 The loose, dry material passing the 2 mm test sieve shall then be divided into 2 subsamples of 500 g ± 5 g by either riffling or quartering, and the weight recorded as $M_{d\ prior}$ for each subsample. A separate maximum dry density determination shall be performed upon each subsample.

3.7 Each subsample shall be stored in an airtight plastic container or kept in a 50°C oven until the test is performed.

4 Maximum Dry Density - Test Procedure

4.1 Attach the filter paper centrally at the base of the top disc using double-sided tape or similar.

4.2 Measure the thickness of the disc (with filter paper attached) in 4 places and record T_1, T_2, T_3 *and* T_4 to 0.01 mm.

4.3 Internally, at the circumference, measure and record the distance, E_1, from the top of the mould to the base of the mould to 0.01 mm.

4.4 Measure and record three further equidistant measurements (E_2, E_3, E_4) around the circumference of the mould in a similar manner.

4.5 Measure and record two internal diameters (D_1, D_2) of the mould at right angles to each other, to 0.01 mm.

4.6 Clamp the base of the mould on to the shaker and pour in approximately 100 mL of water. It may be necessary to use less water if it is found that excessive splashing occurs during the testing see clauses 4.9 and 4.11.

4.7 With the mould in place, set the amplitude to 2 mm. Smaller amplitudes may be desirable when pouring the sand in clause 4.9 to avoid excessive splashing.

4.8 Switch on the shaker.

4.9 Pour all the sample slowly into the water. Around 10-15 seconds pouring time has been found to be successful in minimising trapped air.

4.10 Use a plastic foil to cover the top of the mould to avoid spilling of water/sand during the initial phase.

4.11 Vibrate the mould at an amplitude of about 2 mm. Care should be taken not to spill or lose sample through over-agitation and a smaller amplitude may be required at this stage. Gentle circulation of the sand should be visible. Continue the vibration for at least 2 minutes until no more air bubbles can be seen emerging from the sample. Record vibration time.

4.12 Switch off the shaker.

4.13 Remove the plastic foil and check if there is visible excess water above the sand surface, hence the sample should be fully saturated. If necessary, add additional water using the wash bottle to ensure there is a minimum of excess water above the sand surface. The weight of water added shall be noted. If water is added, the mould should be covered by plastic foil, be returned to the shaker and further agitated until there is a minimum of excess water above the sand surface.

4.14 Remove the plastic foil and place the disc with filter paper facing down, carefully upon the top of the sample surface.

4.15 Remove carefully any excess water and sand that may have escaped above the disc using suction by syringe or similar.

4.16 Using the depth gauge, measure at the circumference down the distance, S_1 from the top of the mould to the top of the disc and record to 0.01 mm.

4.17 Measure and record to 0.01 mm three further equidistant measurements (S_2, S_3, S_4) around the circumference of the mould in a similar manner [these are before the surcharge has been applied].

4.18 Place the surcharge weight gently upon the disc. The surcharge shall be prevented from hitting the sides of the wall of the mould and a steady/cushion may be used. Ensure that the surcharge weight does not bounce on the top disc during vibration.

4.19 Switch on the shaker at an amplitude of 2 ± 0.2 mm and vibrate for 15 seconds.

4.20 Turn off the shaker and remove the surcharge weight.

4.21 Remove carefully any excess water and sand that may have escaped above the disc using suction by syringe or similar.

4.22 Using the depth gauge, measure at the circumference down the distance, S_5, from the top of the mould to the top of the disc and record to 0.01 mm, at the same points as in clause 4.16.

4.23 Measure and record to 0.01 mm three further equidistant measurements (S_6, S_7, S_8) around the circumference of the mould in a similar manner at the same points as in clause 4.17. Ensure clean contact is made with the disc.

4.24 All measurements S_5 to S_8 must be within ± 1 mm of each other. If this has not been achieved, the mould should be returned to the shaker and further agitated and remeasure until this requirement is achieved.

4.25 Ensure any material above the disc or adhering to the mould walls above the disc is carefully removed. Transfer the sample, the material below the disc, into a non-corrosive tray of a known mass, ensuring that any material that might be adhering to the mould walls, filter paper and disc is rinsed into the tray to ensure that no sample is lost.

4.26 Place the tray into the drying oven and the sample shall be dried to a constant mass according to ISO 17892-1.

4.27 When dry, weigh and record the sample mass ($M_{d\ after}$) to 0.1 g. A new determination is required on a new subsample if loss of material $(M_{d\ prior} - M_{d\ after})/M_{d\ prior})\cdot 100\%)$ exceeds 2%.

4.28 Calculate the volume of the subsample as specified in clause 5.3.

4.29 Repeat the procedure from clause 4.4 onwards on the second subsample (prepared in clause 3.6).

4.30 Calculate the maximum dry densities as per clause 5.4.

4.31 If the two $\rho_{d\ max(7\ kPa)}$ values are not within 1.5% of each other when measure to 3 decimal places (i.e. before rounding to 2 places in reporting), then repeat determination until two values are obtained within this requirement.

5 Calculations

5.1 Calculate the average final height *(H)* in mm of each of the subsamples using the formula:

$$H_{(0\ kPa)} = [(E_1 + E_2 + E_3 + E_4) - (S_1 + S_2 + S_3 + S_4) - (T_1 + T_2 + T_3 + T_4)] / 4$$

$$H_{(7\ kPa)} = [(E_1 + E_2 + E_3 + E_4) - (S_5 + S_6 + S_7 + S_8) - (T_1 + T_2 + T_3 + T_4)] / 4$$

5.2 Calculate the average internal diameter *(D)* in mm of the mould using the formula:

$$D = (D_1 + D_2) / 2$$

5.3 Calculate the volume (*V*) in cm³ of each subsample using the formula:

$$V_{(0\ kPa)} = D^2 \cdot H_{(0\ kPa)} \cdot \pi / 4000$$

$$V_{(7\ kPa)} = D^2 \cdot H_{(7\ kPa)} \cdot \pi / 4000$$

5.4 Calculate the maximum dry density ($\rho_{d\ max}$) to 0.01 Mg/m³ using the formula:

$$\rho_{d\ max(0\ kPa)} = M_{d\ prior} / V_{(0\ kPa)}$$

$$\rho_{d\ max(7\ kPa)} = M_{d\ after} / V_{(7\ kPa)}$$

5.5 The reported maximum dry density, $\rho_{d\ max}$, shall be the average maximum dry density of the two 7 kPa subsamples that are within the prescribed tolerance (see clause 4.31).

5.6 Calculate the percentage of material retained on the 2 mm test sieve using the formula:

$$M_{retained\ 2\ mm} = (M_{all} - M_{sieved})/M_{all} \cdot 100\%$$

6 Reporting

6.1 The test report shall affirm that the test was performed in accordance with this test procedure and shall contain the following information:

a) The method of test used;

b) Identification of the specimen tested, e.g. by sample number, borehole number and sample depth;

c) Percentage of material retained on the 2 mm test sieve, $M_{retained\ 2\ mm}$

d) A visual description of the specimen under test, including any observed features noted after testing;

e) Both before and after surcharge application, the maximum dry density of all of the subsamples and the average value of the two subsamples which meet the prescribed tolerance, all expressed in Mg/m³ to 2 decimal places.

f) The amplitude settings used

g) Any deviations from the method above shall be reported

Reference

ISO 17892-1:2014.. Geotechnical investigation and testing — Laboratory testing of soil — Part 1: Determination of water content